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A Prospective Study of the Physiological and Neurobehavioral Effects of Ramadan Fasting in Preteen and Teenage Boys

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ABSTRACT

Background Intermittent fasting during the month of Ramadan, although not obligatory, is commonly practiced by Muslim children.

Objective Our aim was to describe the effects of Ramadan fasting on various physiological and neurobehavioral measures in preteen and teenaged boys.

Design We conduced a prospective cohort study during Ramadan, observed from August 9 to September 11, 2010.

Participants Eighteen healthy Muslim boys (mean age±standard deviation 12.6±1.5 years) were recruited and assessed before, during (1st and 4th weeks), and after Ramadan. Subjects were classified as preteens (aged 9 to 12 years) or teens (aged 13 to 15 years).

Intervention On each clinic visit, participants completed a match-to-sample test, a spatial planning and working memory task, and a working memory capacity test using the Cambridge Neuropsychological Test Automated Battery. Participants were also assessed for their sleep patterns, daily energy expenditure, and dietary intake. Body composition was determined using a dual-energy x-ray scan. Complete blood count, lipid profile analysis, and iron indices were conducted.

Main outcome measures We measured morphologic, metabolic, and neurobehavioral parameters.

Statistical analyses A linear mixed model was used to assess changes in outcome measures. Post hoc pairwise comparisons were performed as necessary with Bonferroni adjustment.

Results Within 1 week of fasting, there was a drop in body fat only in preteens (P=0.001). Reported fat (P=0.004) and protein intake (P=0.037) was higher during Ramadan, but energy expenditure did not change. By the end of Ramadan, there was a significant reduction in hemoglobin (mean±standard error −0.48±0.4 mmol/L) and serum iron (−25.7±31.8 μg/dL [−4.6±5.7 μmol/L]) levels. During week 4, total sleep duration decreased by 1.8 hours. At week 4, performance on the spatial planning and working memory task and working memory capacity test increased significantly (P=0.002), while match-to-sample test performance declined in preteens only (P=0.045).

Conclusions Ramadan fasting was associated with significant changes in body composition, dietary intake, and sleep patterns. Reductions in attention and iron indices were observed in preteens only.
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RAMADAN IS THE NINTH MONTH OF THE ISLAMIC lunar calendar, when Muslims around the world participate in an intermittent fast for 29 to 30 days as a part of their religious duty. Ramadan fasting is different from other religious forms of fasting practiced in Christianity and Judaism. For a fast to be valid, the participant must completely abstain from any form of eating or drinking during the period from dawn to sunset.[1] Because the Islamic lunar calendar is shorter than the solar calendar by 10 to 11 days, Ramadan falls within different seasons each year, and the duration of fasting can vary by season and by region. In most regions, the duration of the fast is 13 to 15 hours; however, at high latitudes, the duration can vary between 9 hours in the winter to 20 hours in the summer. In preparation for

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each fast, Muslims will have their first meal, called *Suhoor*, just before dawn, after which they are not permitted to eat or drink until sunset. The second meal, *Iftaar*, is taken immediately after sunset. The *Iftaar* is culturally designed to be abundant in sweet and fried dishes and can constitute 90% of the daily caloric intake.[2] The number of meals per day is generally reduced to two,[3] as there is often little time remaining to accommodate another meal before bedtime. Consequently, Ramadan fasting has been shown to influence sleep patterns, with a delay in bedtime and reduction in duration of sleep.[4] During the daylight hours, moderate or vigorous forms of physical activity are not recommended when fasting, simply because of the inability to refuel or rehydrate.[5] In addition, because the holy month encourages more engagement in religious/spiritual activities at night, planned physical activity during the month of Ramadan is generally reduced.[6-8]

Several studies have reported changes in body composition due to energy imbalance during Ramadan, but the results are inconsistent and largely lifestyle-dependent.[9-11] Cognitive abilities, psychomotor function, verbal learning, and short-term memory performance have been shown to decrease significantly during fasting conditions by the end of the day.[12] Low blood glucose levels and accumulated sleep loss can both contribute to reductions in certain cognitive functions and overall mood.[13]

Although fasting during Ramadan is obligatory for all Muslims, Islam allows exceptions in certain cases. Children who have not reached puberty are exempt from fasting, although it is not uncommon to find some who practice fasting at 6 or 8 years of age. Importantly, in Muslim countries, the social environment and cultural activities encourage fasting conditions. For example, in one cross-sectional survey of 734 Malaysian Muslim teenage athletes, 100% reported that they practiced Ramadan fasting in 2009.[14]

Knowledge about the effects of Ramadan fasting on the health of young children is poor, mainly because of a scarcity of scientific research in this area.[15,16] A few studies have investigated the effects of Ramadan fasting in children, although they have mainly focused on sports-specific outcomes.[17-19] Because children are actively growing, their nutritional requirements and energy expenditures are quite different from those of adults. The potential negative consequences of Ramadan fasting on body composition, physical activity, sleep, and cognitive ability may impact their ability to successfully engage in active learning at school. The purpose of this prospective cohort study was to describe the effects of Ramadan fasting on several morphologic, metabolic, and neurobehavioral parameters in a cohort of Muslim boys.

METHODS

Institutional Review Board Approval and Informed Consent/Assent

Institutional approval for the study was obtained from the Aspetar—Orthopaedic and Sports Medicine Hospital Scientific Committee. Written informed consent from parents and verbal assent from children were received before data collection.

Study Subjects

The study participants were a convenience sample recruited by word of mouth through area schools in Doha, Qatar. To ensure their ability to complete the study protocol, only participants who reported that they completed the previous Ramadan fast were eligible. Eighteen healthy Muslim boys (mean age±standard deviation 12.6±1.5 years) of Asian ethnic origin who had volunteered to participate in the Ramadan fast were recruited into the study at least 2 weeks before Ramadan and followed for up to 4 weeks after Ramadan. The study was conducted in 2010, when Ramadan was observed from August 11 to September 9. During the study period, the maximum fasting duration in Qatar was 14 hours and 13 minutes, which decreased to 13 hours and 30 minutes by the end of the fasting period. Timing of the *Suhoor* meal was planned to finish just before dawn (3:42 AM to 3:59 AM).

It was not possible to recruit an age-matched control group of nonfasting children from this population due to unavailability of subjects. Only boys were enrolled in this study because preteen and teen girls do not participate in Ramadan fasting during menstruation; therefore, it was not possible to collect a full set of data to determine the effects of Ramadan fasting in girls. Due to cultural sensitivity within the study population, the pubertal status of the boys was not determined. Subjects were instead separated into age groups, with "preteen" indicating subjects 9 to 12 years of age (n=9) and "teen" indicating subjects 13 to 15 years of age (n=9). The sample size of 7 subjects per group was sufficient to detect a difference in body mass of 1 kg with 80% power and 5% type I error rate. It was assumed a difference in the pre- and post-study measures would have a standard deviation of 0.8.

Morphologic and Metabolic Outcome Measures

Body composition, dietary assessments, and physical activity were measured 1 week before Ramadan (baseline), during the 1st and 4th weeks of Ramadan (day 7 and day 28), and 2 weeks (day 14) after Ramadan. Body mass (kg), height (cm), waist circumference (cm), and hip circumference (cm) were recorded according to standard clinical protocols. Body composition was assessed using a dual-energy x-ray scan (GE Medical System Lunar) and enCORE software (version 12.10, GE Medical System Lunar).

A 24-hour recall incorporating digital food record was used for dietary assessment as described by Martin and colleagues.[20] Each participant was given a handheld 3.2-megapixel camera to capture pictures of food plates and any food or drink intake during the 24-hour period (midnight to midnight) 1 week before Ramadan and 1 day during week 2 of Ramadan. The participants were instructed to take a picture of any food or fluid before intake/ingestion. Any items that were subsequently added to the plate were to be photographed separately in a small plate or cup to assist in portion-size evaluation. Finally, plate waste was to be photographed at the end of meal. Use of 24-hour recall with digital record has been validated as an accurate method to assess nutrient intake in young children.[21] During the face-to-face interview, 24-hour recall was undertaken in chronological order of food consumption. The clinical nutritionist used food sample kits to determine portion sizes and noted any instances of missing food item (provided by the 24-hour

digital record). Nutrients were quantified in the 24-hour recall/digital food record using commercially available computer software Nutritionist Pro (version 3.2, 2012, Axxya Systems). The software included an Asian Indian database in addition to the US Department of Agriculture database.

A three-axis accelerometer (Alive Technologies) was used to measure diurnal activity during a 48-hour period. Subjects were instructed to wear the device on their chest at all times, except when bathing. Energy expenditure (kcal/min) was computed automatically and the data were downloaded at each follow-up visit.

Hematological variables were measured 1 day before Ramadan (baseline), at the end of Ramadan (day 28), and 4 weeks after Ramadan (28 days after). Two 10-mL venous blood samples were collected from each subject by venipuncture into ethylenediaminetetraacetic acid and heparinized tubes for blood chemistry analysis (Boehringer Mannheim Automated Analyzer; BM/Hitachi System 717). Hematological investigations included a complete blood count, lipid profile, and iron indices. All blood tests were performed after 10 to 12 hours of fasting; specifically, between 3 PM and 4 PM for samples taken during Ramadan and between 9 AM and 10 AM for samples taken before and after Ramadan.

Neurobehavioral Outcome Measures

Parents were also asked to maintain a 48-hour sleep diary to record the timing of their children's sleep patterns (bed time, wake time, and time taken to get to sleep). Sleep patterns and cognitive tasks were assessed 1 week before Ramadan (baseline), during the first (6th and 7th day) and fourth (27th and 28th day) weeks of Ramadan, and 2 weeks after Ramadan (13th and 14th day from the end of Ramadan). Sleep efficiency was computed as percentage of time asleep compared to the time in bed data from the diary, which was reviewed at each follow-up visit. In addition, the Pittsburgh Sleep Quality Index (PSQI) was used to determine a child's sleep quality. The PSQI is a self-rated questionnaire in which a subject answers questions concerning sleep quality and other sleep parameters within the past month.[22] The PSQI was administered during face-to-face interviews with each subject at clinic visits, using an approach described in a previous report.[23] PSQI assesses seven components of sleep: subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleep medication, and daytime dysfunction. Each component can achieve a score between 0 (better) and 3 (worse), which are summed up to yield a global PSQI score that ranges from 0 to 21. A score >5 is generally associated with poor sleep quality.[22]

The Cambridge Neuropsychological Test Automated Battery was used to administer the Stockings of Cambridge, Match to Sample Visual Search, and Spatial Span tests during morning hours between 8 AM to 1 PM. The Cambridge Neuropsychological Test Automated Battery is a validated computerized assessment tool that uses touchscreen technology to measure cognitive function in children.[24]

To remove the potential for learning effects during the study, a familiarization test was completed 1 week before the baseline assessment (2 weeks before Ramadan, with baseline at 1 week before Ramadan).

Statistical Analysis

All statistical analyses were performed using SPSS Statistics (version 21.0, 2012, IBM Corporation). Necessary assumptions of statistical tests, namely, the normality of data, homogeneity of variance, and presence of outliers, were tested. A linear mixed model was used to assess for main effects of time on changes in outcome measures. An interaction of Time×Age was added to determine the relationship of

Table 1. Body composition of Muslim preteen and teen boys (n=18) 1 week before (baseline), at week 1 and 4, and 2 weeks after observing intermittent Ramadan fasting

	Preteen[a] (n=9)				Teen[b] (n=9)			
Body composition	Baseline	Week 1 of Ramadan	Week 4 of Ramadan	2 Weeks after Ramadan	Baseline	Week 1 of Ramadan	Week 4 of Ramadan	2 Weeks after Ramadan
	←mean±standard error→							
Body mass (kg)	36.8±7.4	37.1±7.5	37.2±7.6	37.9±7.9**	53.9±10.5	54.6±10.8*	55.4±11.0**	55.9±10.5**
Body mass index[c]	16.8±0.7	17.0±0.8	17.1±0.8	17.2±0.8**	19.6±0.7	19.8±0.8*	20.1±0.8 **	20.3±0.8**
Fat mass (kg)[d]	9.0±2.9	8.2±2.3	9.2±3.2	9.5±3.3	13.3±7.0	13.3±6.8	13.8±7.0	14.2±7.1
Lean mass (kg)[d]	26.9±2.3	27.5±2.3*	27.4±2.3	27.8±2.3*	38.5±2.1	39.3±2.2**	39.6±2.2**	39.7±2.1**
Body fat (%)[d]	22.6±2.7	21.9±2.6*	22.6±2.6	22.9±2.7	23.9±2.5	23.5±2.4	24.0±2.5	24.5±2.6
Waist circumference (cm)	60.3±2.4	60.3±2.8	61.2±2.7	62.9±2.9	71.0±2.4	71.1±2.8	72.3±2.7	74.2±2.9
Hip circumference (cm)	74.1±2.9	76.0±2.7	75.7±3.2	77.1±2.6	86.4±2.9	87.6±2.7	86.6±3.2	89.3±2.6

[a]Aged 9 to 12 y.
[b]Aged 13 to 15 y.
[c]Calculated as kg/m^2.
[d]Using a dual energy x-ray absorptiometry scan.
*Significantly different compared with baseline $P<0.05$.
**Significantly different compared with baseline $P<0.001$.

outcomes to age. Post hoc pairwise comparisons were performed as necessary with Bonferroni adjustment. Statistical significance was assumed to be at $P<0.05$.

RESULTS

Body Composition, Dietary Intake, and Activity Patterns during Ramadan

Table 1 shows the changes in body composition before, during, and after Ramadan in the study cohort. Body mass showed significant interaction with Time×Age Group ($F[3, 48]=4.3$; $P=0.009$). Mean body mass in preteens was unchanged by week 4, and in teens there was a significant increase at week 4 compared with baseline ($P<0.001$) and week 1 ($P=0.022$). In both groups, the mean body mass 2 weeks after Ramadan was significantly higher than at baseline ($P<0.001$). Overall, there was a linear increase in fat mass ($F[3, 47]=20.9$; $P<0.001$), lean mass ($F[3, 47]=16.1$; $P<0.001$), and percent body fat ($F[3, 47]=9.0$; $P<0.001$) with time, but there was no Time×Age Group interaction. Both groups showed a significant increase in lean mass at week 1 compared with baseline ($P<0.001$) and percent body fat at week 4 of Ramadan, compared with week 1 ($P=0.025$). The increases in waist and hip circumferences at week 4 were not significantly different compared with the baseline in both groups; however, waist and hip measurements at 2 weeks after Ramadan were significantly higher compared with the baseline ($P<0.001$ and $P=0.012$, respectively).

During the month of Ramadan, study participants had only two main meals per day (*Suhoor* at the beginning of fasting and *Iftaar* at the break of fasting) compared with three meals per day before Ramadan. Although reported caloric intake within the study cohort was higher during Ramadan, it did not reach statistical significance (Table 2). Also during Ramadan, teens increased their reported protein intake significantly ($P=0.011$), and preteens increased reported fat ($P=0.007$) and fiber ($P=0.008$) intake significantly. There were no changes in reported carbohydrate or other dietary parameters; however, there was a nonsignificant increase in sugar ($P=0.334$) and vitamin C ($P=0.335$) intake during Ramadan among preteens.

During Ramadan, the peak activity during the day shifted from 1:00 PM to 6:00 PM to later in the evening at 4:00 PM to 9:00 PM (Figure). During Ramadan, children had two bedtimes, as sleep was interrupted when they had to wake up for *Suhoor* meal just before dawn. The mean time to bed was 12:41 AM at the end of week 1, which gradually shifted to 1:33 AM by the end of Ramadan. However, overall mean±standard error (SE) total energy expenditure before Ramadan (1.02±0.3 kcal/min) was similar to that during Ramadan (week 1, 1.06±0.3 kcal/min; week 4, 1.15±0.3 kcal/min) and 2 weeks after Ramadan (0.97±0.3 kcal/min).

Sleep Pattern and Attention

Both teens and preteens did not show any changes in PSQI scores during Ramadan month. Overall, mean±SE PSQI score representing sleep quality during Ramadan (5.1±2.5) was comparable with pre-Ramadan month (5.1±2.5; $P=0.939$). Indicators of poor sleep quality (PSQI >5) were more common in teens (55.6%) compared with preteens (22.2%) at baseline and were not affected during Ramadan (57.1% and 33.3%, respectively).

Table 3 represents data pertaining to the 48-hour sleep diary maintained by parents. We excluded sleep data from five subjects who provided incomplete diaries. The total sleep time before Ramadan (9.3±0.5 hours) was significantly reduced by the 4th week of Ramadan (7.5±0.7 hours;

Table 2. Mean 24-hour dietary intake of Muslim preteen and teenage boys (n=18) 1 week before Ramadan and week 2 during Ramadan fasting

	Total		Preteen[b]		Teen[c]	
Nutrients[a]	Before Ramadan	During Ramadan	Before Ramadan	During Ramadan	Before Ramadan	During Ramadan
	← *mean±standard error* →					
kcal	2,456.1±160.1	2,795.9±140.2	2,455.6±233.4	2,791.4±200.2	2,456.5±233.4	2,800.9±209.8
Protein (g)	89.2±7.3	109.6±7.4*	102.9±9.5	109.1±10.4	75.5±9.5	110.5±11.0*
Carbohydrates (g)	346.6±25.9	362.0±20.5	326.2±37.1	346.5±28.7	367.1±37.1	378.6±30.2
Fat (g)	77.7±5.9	100.1±5.7**	77.7±8.5	106.9±7.7**	77.6±8.5	92.5±8.1
Sodium (mg)	2,367.5±225.1	2,564.2±193.6	2,182.6±321.6	2,602.7±274.0	2,552.3±321.6	2,517.6±289.2
Vitamin C (mg)	91.8±19.8	146.7±39.9	80.4±28.7	136.9±57.1	103.1±28.7	156.1±59.4
Calcium (mg)	697.1±59.9	865.4±95.5	637.3±84.7	915.3±134.2	756.9±84.7	798.1±142.3
Dietary fiber (mg)	16.8±1.6	24.0±3.4*	14.1±2.1	24.9±4.9**	19.4±2.1	22.7±5.0
Sugar (mg)	81.9±12.7	108.4±11.6	90.9±18.4	105.4±16.4	82.9±18.4	111.6±17.3

[a]Mean nutrient intake assessed using a 24-hour dietary recall and digital image record.
[b]Aged 9 to 12 y.
[c]Ages 13 to 15 y.
*Significantly different compared with before Ramadan $P<0.05$.
**Significantly different compared with before Ramadan $P<0.01$.

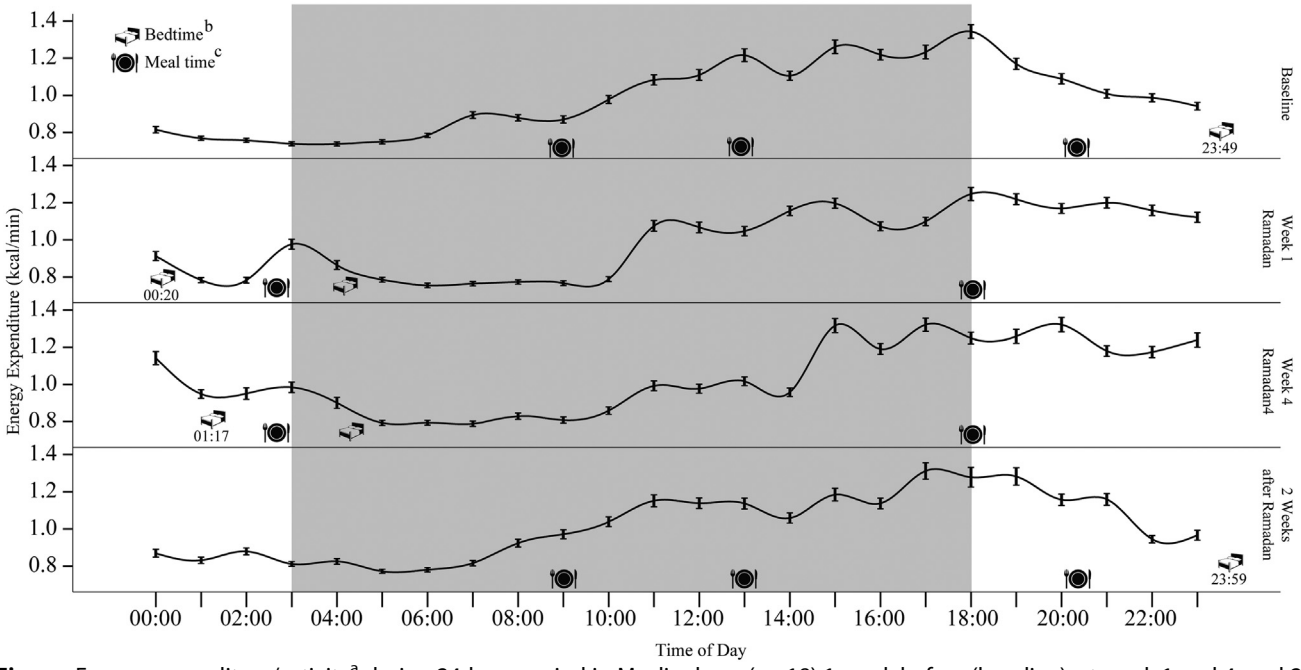

Figure. Energy expenditure/activity[a] during 24-hour period in Muslim boys (n=18) 1 week before (baseline), at week 1 and 4, and 2 weeks after observing Ramadan fasting. [a]Energy expenditure was assessed using triaxial accelerometer based on 48-hour activity. [b]Mean bedtime of participants based on 48-hour sleep diary maintained by parents. Precise bedtimes after the *Suhoor* meal during Ramadan could not be determined. [c]Typical meal times are shown.

Table 3. Sleep patterns and neurobehavioral test scores in Muslim boys (n=18) 1 week before (baseline), at week 1 and 4, and 2 weeks after observing Ramadan fasting

Variables	Baseline	Week 1 of Ramadan	Week 4 of Ramadan	2 Weeks after Ramadan	*P* value
	←——————*mean±standard error*——————→				
Sleep parameters[a]					
Sleep duration (h)	9.3±0.5[b*]	9.8±0.5[b**]	7.5±0.7	9.3±0.5[b*]	0.001
Sleep efficiency (%)	85.9±3.7	88.0±2.8	87.7±3.3	94.5±1.6[c*]	0.011
Sleep initiation (min)	16.7±2.0	17.7±3.5	13.6±2.1	16.7±1.8	0.437
Cognitive tests[d]					
Spatial Span[e]					
Span length (0 to 9)	6.5±1.0	7.4±0.9[c*]	7.2±1.2	7.5±1.0[c**]	0.002
Match to Sample Visual Search[f]					
Percent correct	93.2±3.2	92.5±4.6	90.2±8.1	90.2±9.7	0.254
Stockings of Cambridge[g]					
Problems solved in minimum moves (0 to 12)	6.4±2.0	7.6±1.5	8.4±1.7[c**]	8.3±1.8[c**]	0.002

[a]Sleep parameters were assessed using 48-hour sleep diary maintained by parents.
[b]Significantly higher compared with week 4.
[c]Significantly higher compared with baseline.
[d]Cognitive tasks were assessed using computerized touch screen device (The Cambridge Neuropsychological Test Automated Battery).
[e]Spatial Span determines working memory capacity.
[f]Match to Sample Visual Search is a speed/accuracy trade-off task that assesses attention.
[g]Stockings of Cambridge assesses planning ability.
*$P<0.05$.
**$P<0.01$.

Table 4. Complete blood cell count profile in Muslim boys (n=18) 1 day before Ramadan, at the end of Ramadan (week 4), and 4 weeks after observing Ramadan fasting

Variable	Baseline	Week 4 of Ramadan	1 month after Ramadan	*P* value
	←——————*mean±standard error*——————→			
Complete blood count profile				
White blood cell count ($\times 10^9$/L)	6.3±0.3	6.6±0.3	6.8±0.5	0.206
Red blood cell count ($\times 10^{12}$/L)	5.0±0.1	4.9±0.1	5.1±0.1[a*b**]	0.002
Corpuscular volume (fL)	80.3±1.7[b***c***]	78.3±1.6	77.8±1.6	<0.001
Corpuscular hemoglobin (pg)	27.5±0.6[c**]	26.9±0.7	26.6±0.7	0.011
Corpuscular hemoglobin concentration (g/dL)	34.1±0.1	34.1±0.2	34.2±0.2	0.755
Red cell distribution width (%)	15.1±0.2[b**c***]	14.6±0.2	14.14±0.3	<0.001
Platelets ($\times 10^9$/L)	295.3±14.3	292.2±14.7	296.7±15	0.824
Platelet volume (fL)	8.2±0.3	7.9±0.2	7.8±0.2	0.252
Lipid profile				
High-density lipoprotein cholesterol (mmol/L)[d]	1.2±0.1[c**]	1.3±0.1[c***]	1.1±0.03	<0.001
Low-density lipoprotein cholesterol (mmol/L)[d]	2.3±0.1	2.4±0.1	2.3±0.1	0.172
Triglyceride (mmol/L)[e]	0.88±0.1[b*c***]	0.74±0.1	0.66±0.1	<0.001
White blood cells				
Neutrophils (%)	51.9±1.5	50.4±1.4	51.5±2	0.637
Neutrophils ($\times 10^9$/L)	3.4±0.2	3.6±0.4	3.3±0.2	0.277
Lymphocytes (%)	35.8±1.4	37.9±1.4	35.3±1.9	0.280
Lymphocytes ($\times 10^9$/L)	2.5±0.1[b*c**]	2.3±0.1	2.2±0.1	0.004
Monocytes (%)	8.5±0.3	7.9±0.2	8.9±0.4[b**]	0.005
Monocytes ($\times 10^9$/L)	7.9±0.2	8.9±0.4[a**]	8.5±0.3	0.005
Iron indices				
Hemoglobin (g/dL)	13.6±0.3[b**]	13.2±0.3	13.6±0.4[b**]	<0.001
Serum iron (μg/dL)[f]	17.7±1.6[bc**]	13.1±1.4	12.7±1.7	0.001
Iron-building capacity (μmol/L)	66.3±1.6[c**]	67.7±1.5[c***]	63.8±1.5	<0.001
Transferrin saturation (%)	27.3±2.6[b**c*]	19.9±2.3	20.6±3.0	0.003

[a]Significantly higher than baseline.
[b]Significantly higher than Week 4 of Ramadan.
[c]Significantly higher than 1 month after Ramadan.
[d]To convert mmol/L cholesterol to mg/dL, multiply mmol/L by 38.7. To convert mg/dL cholesterol to mmol/L, multiply mg/dL by 0.026. Cholesterol of 5.00 mmol/L=193 mg/dL.
[e]To convert mmol/L triglyceride to mg/dL, multiply mmol/L by 88.6. To convert mg/dL triglyceride to mmol/L, multiply mg/dL by 0.0113. Triglyceride of 1.80 mmol/L=159 mg/dL.
[f]To convert μg/dL iron to μmol/L, multiply μg/dL by 0.179. To convert μmol/L iron to μg/dL, multiply μmol/L by 5.5866. Iron of 17.7 μg/dL=3.17 μmol/L.
*$P<0.05$.
**$P<0.01$.
***$P<0.001$.

P=0.043). Sleep efficiency before Ramadan was similar during the first and fourth week of Ramadan; however, sleep efficiency was markedly increased 2 weeks after Ramadan (94.5%; $P<0.001$).

At baseline, all neurobehavioral test scores for the study participants were within normal ranges compared with published age-specific normative data.[25] From baseline through week 4 of Ramadan, the overall score on the attention test (Match to Sample Visual Search) showed a nonsignificant decline in accuracy from 93.2% to 90.2% (P=0.254), perhaps because of an improvement in the mean correct reaction times (P=0.0499). On the other hand, both problems solved in minimum moves on Stockings of Cambridge (a measure of spatial planning) and span length on Spatial Span (a measure of working memory) improved significantly (P=0.002 in each) (Table 3) by the end of Ramadan, compared with the baseline values. There was an interaction effect of Time×Age on Match to Sample Visual Search accuracy (P=0.045), suggesting that younger participants had a tendency to show poor attention in the final week of Ramadan;

however, there was no significant Time×Age interaction in either the problems solved in minimum moves in the Stockings of Cambridge (P=0.231) or span length in the Spatial Span (P=0.987).

Complete Blood Counts, Lipids, and Iron Indices

There was no change in white blood cell count, but monocytes increased after 4 weeks of fasting (Table 4); however, there was a reduction in the mean corpuscular volume at the end of Ramadan that could be related to the observed decrease in red blood cell distribution. There was a significant reduction in mean hemoglobin by the end of Ramadan (P<0.001), which was restored 1 month after Ramadan (P<0.001). Triglyceride levels were significantly reduced at the end of Ramadan (P=0.020) and were sustained 1 month post Ramadan (P<0.001). Mean serum iron level and mean transferrin saturation were significantly lower by the end of Ramadan and were not restored even 1 month after Ramadan (P=0.003).

DISCUSSION

This is the first study to comprehensively describe the longitudinal physiological and neurobehavioral changes in a cohort of preteen and teenaged boys who chose to fast during Ramadan. In Muslim-majority countries, it is common to see young children voluntarily participate in the Ramadan fast, which raises questions about the effects on growth and metabolism. In addition, Ramadan often coincides with the school year; therefore, the effects of fasting on activity, sleep, and cognitive function in children are potentially significant. Despite several published studies reporting the effects of Ramadan fasting in adults,[1,26,27] the effects of the Ramadan fast are less clear in children.

The increase in body mass found in the teen group after Ramadan was inconsistent with the results of studies among adults that showed no change in body mass[10,28-30] or showed a body mass reduction.[9,31] It has been shown that disruption of eating cycles impacts the circadian rhythm[32] and further excess fat intake could result in abnormal clock and clock-controlled gene expression in the liver.[33] The increase in fat intake and modification of the circadian clock during Ramadan may have impacted negatively on regular metabolic control and, thus, contributed to weight gain in teens. During Ramadan, fat intake was higher in preteens (P=0.007), but mean±SE weight gain in teens post Ramadan was 1.5±0.6 kg (P<0.001) compared with 0.4±0.6 kg (P=0.060) in preteens, despite a similar circadian shift between the two age groups. The absence of a control group makes it difficult to evaluate the observed change in the context of the normal expected body mass change in children of similar age groups. However, in a recent study,[17] North African boys of a similar age showed no changed in body weight after 1 month of Ramadan fasting. Previous studies have reported a decrease in body fat percentage in adult athletes during Ramadan,[9,34] although there was no significant change in body fat percentage in this cohort. Changes in waist and hip circumference data were unremarkable at the end of Ramadan, similar to those seen in studies in adults.[29] Given the scarcity of data, it is prudent to limit comparisons between children and adults with regard to the impact of the Ramadan fast on body composition.

During Ramadan, it is common for Muslims to feast on foods that are high in carbohydrates and fat.[1,35] This is consistent with the findings of the current study in a younger population. Such changes in dietary habit may contribute to a positive energy balance, thereby affecting body composition. Previous studies have reported reductions or no changes in food intake during Ramadan.[27,36] Among preteens, there was a significant increase in fat intake during Ramadan, and it likely contributed to the rise in body fat percentage after the initial reduction in week 1. The small increase in vitamin C intake may be due to increased consumption of fruits, which is common among Muslims during Ramadan,[37] although this increase was only seen in preteens and was not statistically significant. In other forms of fasting rituals, it was demonstrated that intake of calcium is decreased during periods of fasting[38,39]; however, in this study, there was a marginal increase in reported calcium intake during Ramadan fasting.

Ramadan is unique because fasting occurs during the daylight hours only. As such, there is a major shift in the timing of meals, which contributes to changes in physical activity patterns and sleep. Findings of a 1- to 2-hour shift in activity and bedtimes among children in this study (Figure) during Ramadan are in agreement with some reports in adults.[10,11] Two studies reported a decline in energy expenditure in adults during Ramadan,[8] although there was no change in the mean energy expenditure in this cohort. Inconsistencies in energy expenditures across various reports may be related to differences in the season in which Ramadan was observed. In this study, which was conducted in 2010, Ramadan was observed during the summer months; therefore, school was not in session and opportunities for physical activity were higher. On the other hand, throughout the study period, the outdoor conditions were hot (mean temperature ranging from 33° to 39°C), which may have discouraged outdoor physical activity during the daytime. The lack of a structured schedule during the summer may have introduced variability in that some children may have preferred to maximize play time in the summer, while others may have chosen to stay indoors and rest during the time of fasting.

The reduction in overall sleep duration as Ramadan progresses is similar to that commonly reported for adults.[4,40] It is noteworthy that the last 10 days of Ramadan carry more importance for Muslims than the first 20 days. In preparation for the end of Ramadan festival (*Eid al Fitr*), Muslims engage in additional late-night prayers and shopping. The loss in total sleep time in the last week of Ramadan might be attributable to additional late-night activities. After Ramadan, when diurnal patterns begin to revert back to pre-Ramadan patterns, total sleep time began to recover. In the present study, habitual total sleep duration was nearly restored 2 weeks after Ramadan (Table 3).

It is important to highlight that the 2-hour reduction in total sleep time during Ramadan did not negatively impact sleep efficiency. According to clinical guidelines, sleep efficiency >85% reflects a normal sleep pattern. Given that total sleep time was substantially decreased during the fourth week of Ramadan, it is likely that the children had a greater sleep debt and increased sleep drive. Therefore, although counterintuitive, this increased sleep efficiency may reflect an increase in sleepiness during and after Ramadan.[8,13] It is important to highlight that the study was carried out in a

free-living condition during the summer. As such, it is anticipated that in the years that Ramadan falls during the school year, the introduction of school commitment between 7 AM and 1 PM (ie, the usual school schedule in the Middle East, where this study was conducted), requiring an early morning wakeup time along with a 6-hour school day, would create an additional challenge for children to modify their sleeping habits.

Reaction time and alertness, as well as mood, have been reported to decline during Ramadan in adults.[12,41] These changes have negative consequences on cognitive function during the daytime.[12] The findings of this study suggest that although working memory capacity and spatial planning ability were improved by the Ramadan fast in children, attention scores were reduced in preteens. Together these findings suggest that cognitive function may be affected at certain times of the day, but additional studies are needed. When considered with the findings on sleep, these results suggest that recovery of total sleep time after Ramadan may have contributed to improvements in cognitive function.[41] The absence of a control group in this study prevents us from making any conclusions regarding the clinical significance of improvements in working memory capacity and spatial planning during the last week of Ramadan, which may be due to a learning effect.

A significant reduction in triglycerides and iron indices was consistent with findings from adult studies.[3,10,42] In contrast to studies that showed intermittent fasting decreases immune cell proliferation in adults by reductions in leukocytes, lymphocytes, and monocytes, this study showed an increase in monocyte counts.[43,44] However, the values were within normal range.

The strength of this study was that all subjects completed 30 days of fasting and were available at follow-up with complete data. However, there are a few limitations to this study. The lack of a control cohort limits our ability to determine the causal effect of fasting on metabolic and cognitive end points, and the small convenience sample size limits generalizability of the findings to the wider population. It was not possible to obtain consent from the participants to evaluate pubertal status using Tanner staging; therefore, it is unclear to what extent hormones are a factor in our observations. The mean duration of fasting in this study was approximately 14 hours. The findings of this study cannot be generalized to other settings that experience longer days (eg, daylight can last up to 17 hours in the United Kingdom or 20 hours in Sweden in August). Cognitive tests were performed only during the morning in an attempt to match the timing of school activity; however, it is important to evaluate the effects of Ramadan fasting on cognitive tasks near the end of the day, when children are in a hypoglycemic state. Self-reported dietary assessment is often associated with under/overreporting of nutrient intake in this age group.[45] To help minimize bias, a digital food record was used in combination with the 24-hour recall. Finally, the study was conducted during the summer school break, and it can be anticipated that the effects of Ramadan fasting would be more pronounced with the introduction of school commitment. Adequate sleep at night is an essential for effective cognitive performance during school time. Additional studies should consider objective measurement of sleep using actigraphy or portable sleep monitors. Larger, matched cohort studies with a nonfasting group that take into account the time of year and the geographic location are needed to better understand the health effects of Ramadan fasting on children.

CONCLUSIONS

During Ramadan, a cohort of preteen and teenaged boys showed major changes in sleep and diet, which had impacts on body composition, attention, and iron indices, particularly among preteens. Future studies would benefit from a more rigorous study design, including a control group.

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STATEMENT OF POTENTIAL CONFLICT OF INTEREST

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